Advanced Aero-Propulsive Mid-Lift-to-Drag Ratio Entry Vehicle for Future Exploration Missions.
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Introduction: NASA is currently looking well into the future toward realizing Exploration mission possibilities to destinations including the Earth-Moon Lagrange points, Near-Earth Asteroids (NEAs) and the Moon. These are stepping stones to our ultimate destination – Mars. New ideas will be required to conquer the significant challenges that await us, some just conceptions and others beginning to be realized. Bringing these ideas to fruition and enabling further expansion into space will require varying degrees of change, from engineering and integration approaches used in spacecraft design and operations, to high-level architectural capabilities bounded only by the limits of our ideas. The most profound change will be realized by paradigm change, thus enabling our ultimate goals to be achieved. Inherent to achieving these goals, higher entry, descent, and landing (EDL) performance has been identified as a high priority. Increased EDL performance will be enabled by highly-capable thermal protection systems (TPS), the ability to deliver larger and heavier payloads, increased surface access, and tighter landing footprints to accommodate multiple asset, single-site staging. In addition, realizing reduced cost access to space will demand more efficient approaches and reusable launch vehicle systems. Current operational spacecraft and launch vehicles do not incorporate the technologies required for these far-reaching missions and goals, nor what is needed to achieve the desired launch vehicle cost savings. To facilitate these missions and provide for safe and more reliable capabilities, NASA and its partners will need to make ideas reality by gaining knowledge through the design, development, manufacturing, implementation and flight testing of robotic and human spacecraft. **To accomplish these goals, an approach is recommended for integrated development and implementation of three paradigm-shifting capabilities into an advanced entry vehicle system with additional application to launch vehicle stage return, thus making ideas reality.** These paradigm shifts include the technology maturation of *advanced flexible thermal protection materials onto mid lift-to-drag ratio entry vehicles*, the development of *integrated supersonic aero-propulsive maneuvering*, and the implementation of *advanced asymmetric launch shrouds*. These paradigms have significant overlap with launch vehicle stage return already being developed by the Air Force and several commercial space efforts. Completing the realization of these combined paradigms holds the key to a high-performing entry vehicle system capability that fully leverages multiple technology benefits to accomplish NASA's Exploration missions to atmospheric planetary destinations.

Summary: In the 1960s-70s, NASA developed a sound foundation for EDL technology enabling decades of atmospheric entry planetary missions. However, the technology limit of these capabilities has been reached. In the last decade, NASA entry vehicle development investments have been almost exclusively focused on low aerodynamic lift hypersonic designs, such as inflatable and deployable decelerators. Advancements in these vehicle classes will undoubtedly be important for some missions. However, low-lift entry vehicle advancements will only provide additional capability for missions that do not require the landing accuracy precision, reduced entry acceleration loads, or increased surface access afforded by aero-propulsive augmented mid-L/D entry vehicles. This class of entry vehicle augments a rigid mid-L/D slender body shape with additional deployed flexible or rigid aerodynamic surface and combines it with axial propulsion initated at supersonic conditions. Use of a propulsive capability in the high transonic/supersonic Mach number regime enables increased altitude and decreased velocity in addition to propulsive pitch-around vehicle transition to the powered descent and landing phase. Such an advanced entry system also represents an EDL paradigm altering technology development path which would change the reference basis for rapid payload and crew access after landing, mission reliability, total cost, landed payload capability, landing site access and landing precision. The entry performance benefits of moderate and higher L/D in combination with decreased ballistic number have been evaluated by the technical community [1]. Benefits characterized in these studies include those identified above. Another paradigm shifting approach would be to reduce launch shroud constraints on the entry vehicle. Historical launch shroud constraints have limited moderate L/D vehicles to configurations compatible with cylindrical launch shrouds. The impact of this paradigm is borne out by recognizing how configurations such as the ellipsled have been studied for over a decade, most recently by the EDL-SA, whereas no significant studies have evaluated configurations that go beyond the cylindrical launch shroud. Yet, the Air Force has invested in the

development of elliptic cross-section launch shrouds to a near PDR level that may be leveraged for our goals [2]. Increased launch shroud volume enables the mid L/D hypersonic entry vehicle class to achieve functional aerodynamic area comparable to inflatable or deployable low L/D systems. Figure 1 compares the lift and drag area of three configurations in a drag polar format, illustrating how a practical mid L/D shape of 24-meter length and 16-meter span can aerodynamically outperform a 23-meter diameter 65-degree sphere cone.

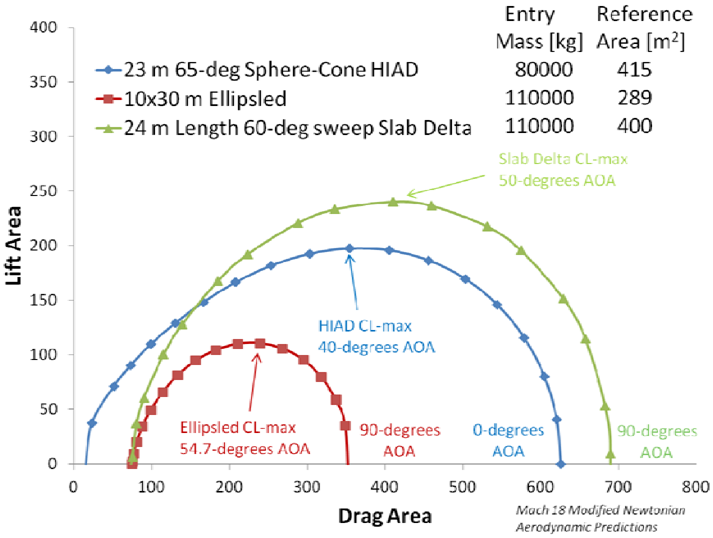

Figure 1. Drag polars for three hypersonic entry configurations based on modified Newtonian aerodynamics.

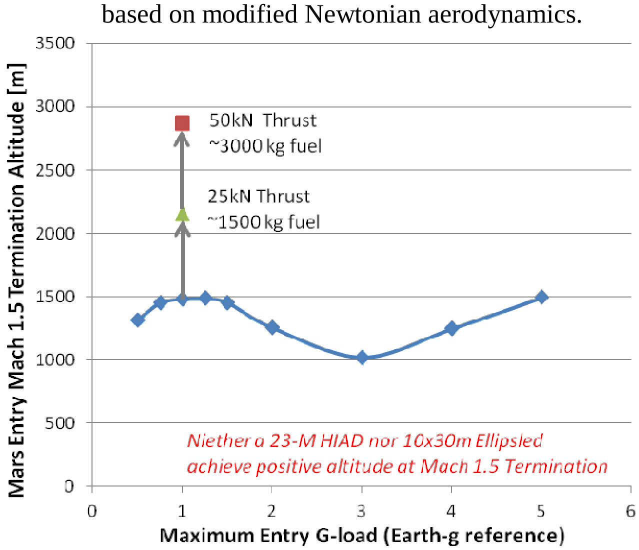

Figure 2. Mars Entry Performance for a slab delta with 60-degree sweep angle and 110000 kg entry mass.

Combined use of the suggested three highly feasible technology advancements has been evaluated with preliminary 3-DOF Mars entry trajectory simulations [3]. These simulations used a unique trajectory framework applied to a slab-delta leveraging a non-cylindrical launch shroud approach with flexible surface augmentation of the entry vehicle to yield aerodynamics as shown in Figure 1. The entry vehicle was assumed to be 110,000 kg and has a planform area comparable to a 23-m HIAD, yielding the altitude performance versus maximum entry g-load shown in Figure 2. Benefits of a supersonic aero-propulsive maneuver with 25 and 50% thrust-to-weight ratios are also illustrated in Figure 2. These high transonic staging conditions are sufficient to enable a traditional propulsive pitch around maneuver prior to vehicle staging, retro-propulsion and landing with less than two Earth-g's of thrust. For comparison, the EDL-SA HIAD and Ellipsled configurations typically used more than three Earth-g's of retro-propulsive thrust initiated at Mach 2 or higher.

The proposed mid L/D approach could also provide reduced development and certification costs, as well as increased reliability compared to large area deployable entry systems. Reduced cost would be enabled by decreasing the need for multiple flight tests to validate robustness and failure modes - an opinion formulated by recognizing that all current large area flexible aerodynamic systems (e.g. sub/super-sonic parachutes) require costly and lengthy flight test programs for certification and qualification supporting human rated and robotic missions. Examples include the ORION Capsule Parachute Assembly System (CPAS) as well as Mars Science Lab (MSL) supersonic parachute. It should be noted that a larger supersonic parachute was not implemented for MSL in large part because of the qualification/certification cost. The proposed mid L/D approach would realize significant total cost and ultimate reliability benefits by enabling ground based development, qualification and certification requiring only a final flight demonstration to validate the technology and full scale designs.

References: [1] Lafleur, J.M., and Cerimele, C.J., "Mars Entry Bank Profile Design for Terminal State Optimization", Journal of Spacecraft and Rockets, Vol. 48, No. 6, Nov-Dec 2011. [2] Ochinero, T., Deiters, T., Higgins, J., Brandon, A., Blades, E., and Newman, J., III, "Design and Testing of a Large Composite Asymmetric Payload Fairing," AIAA-2009-2696, 50th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Palm Springs, CA, Apr 2009. [3] Campbell, C.H., "Specific Energy Gradient Based Entry Trajectory Performance", internal evaluations, 2012.

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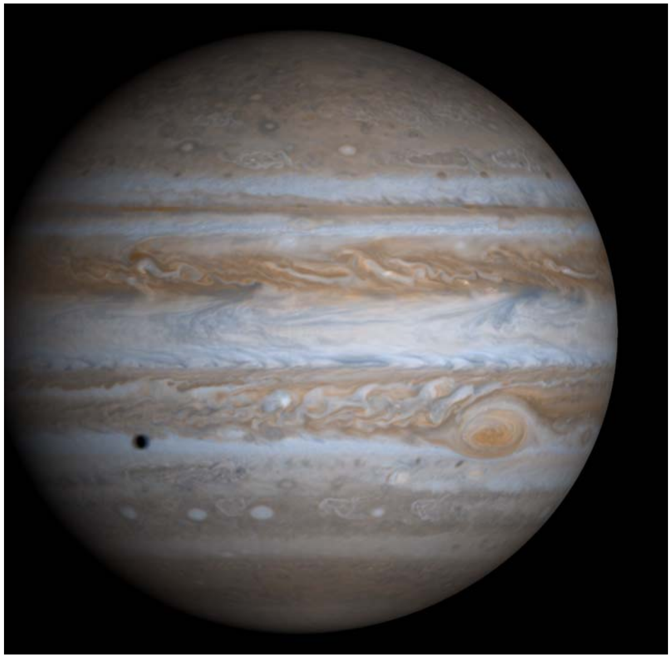

Concepts and Approaches for Mars Exploration

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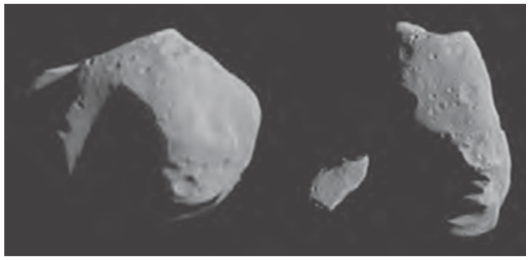

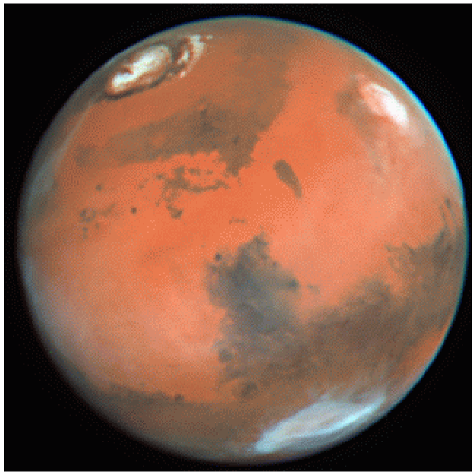

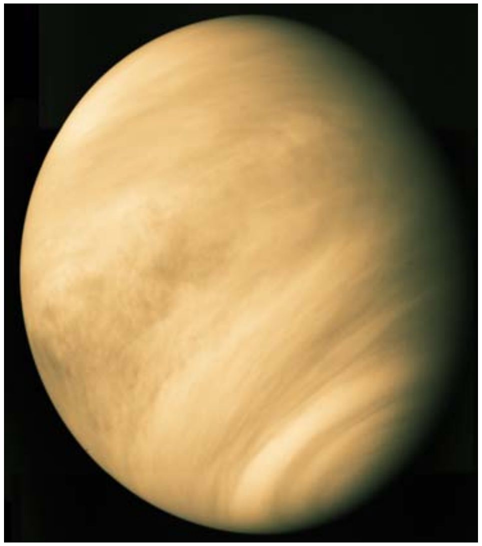

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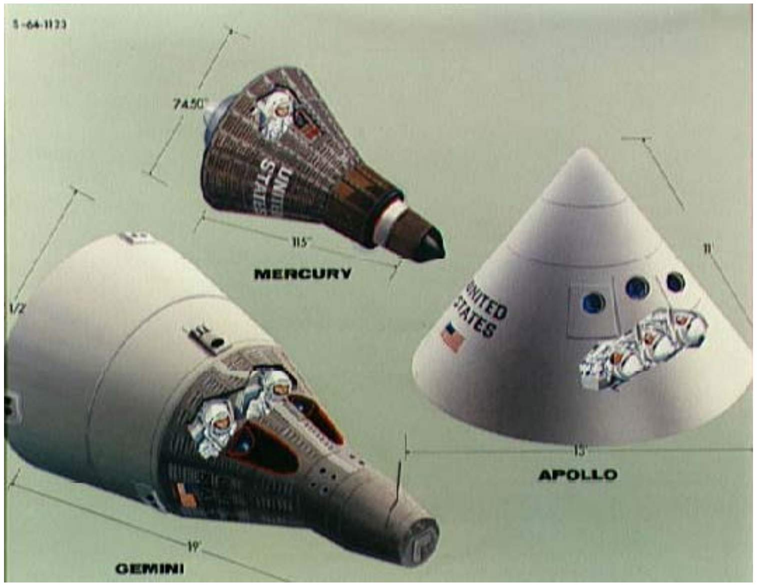
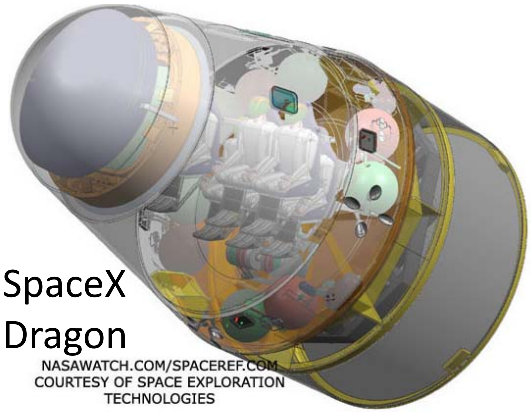
- D.J. Picetti – Boeing Defense, Space and Security, Networks and Space Systems Division
- B. Hassan – Sandia National Labs – Applied Aerospace Systems Analysis Department
- M.W. Kniskern – Sandia National Labs – Aerospace Systems Analysis Department

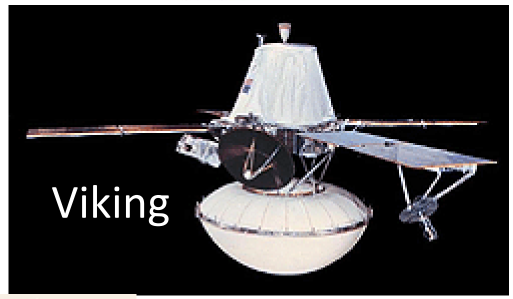
Blunt Hypersonic Entry Vehicles

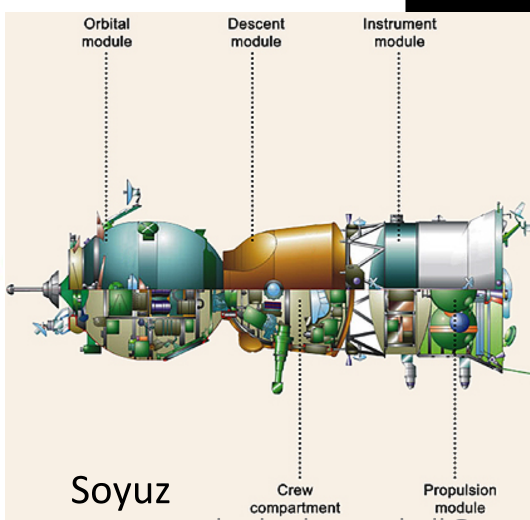
Majority of entry spacecraft are blunt vehicles flown with low lift-drag at trim conditions



SpaceX Dragon

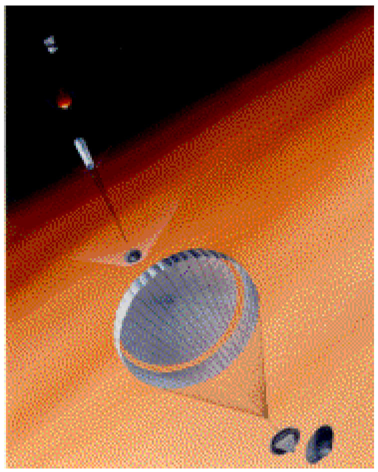


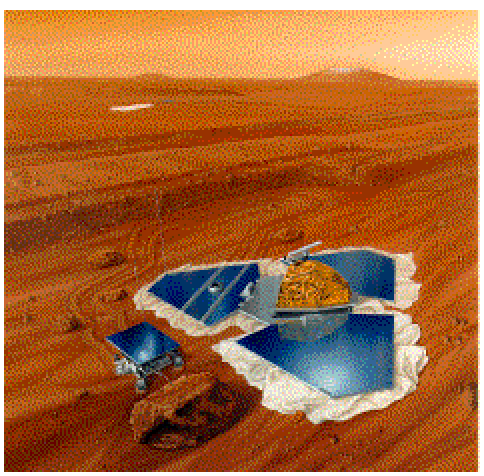


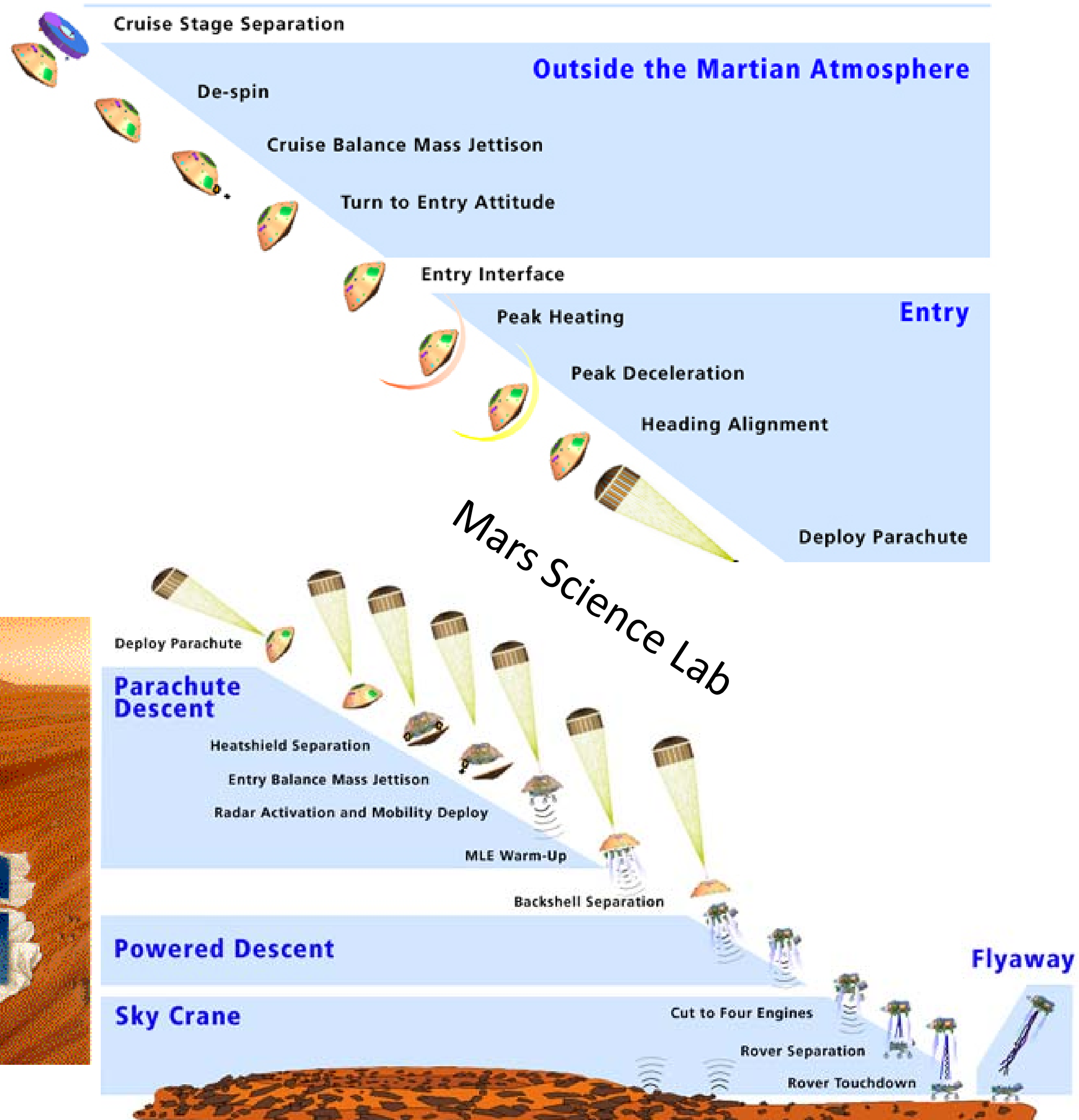


Blunt Vehicle Landing Systems

Pathfinder/Sojourner



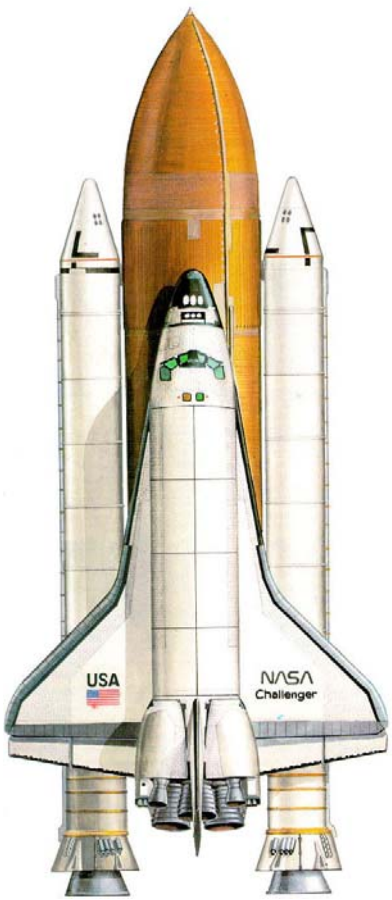


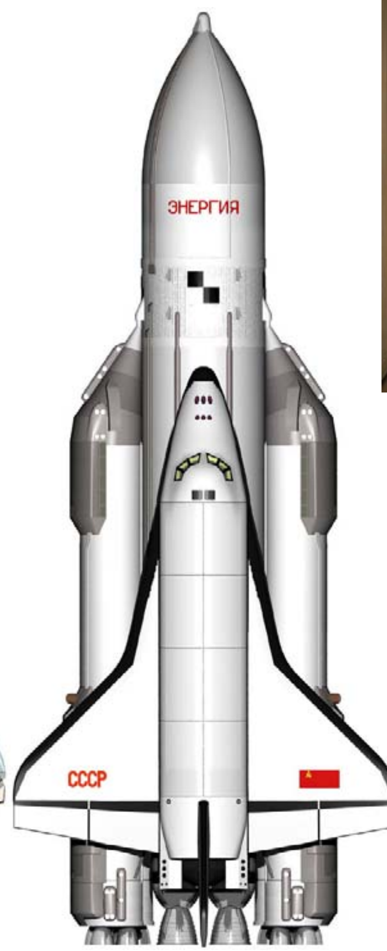


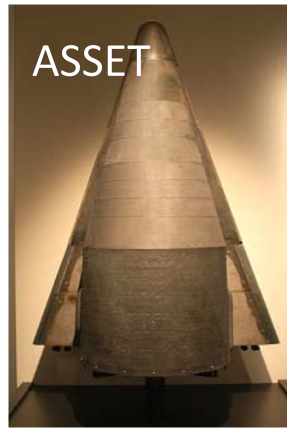
Mars Science Lab

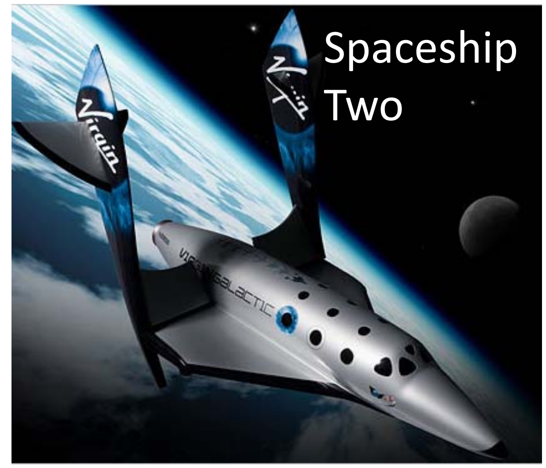
Lifting Entry Vehicles

Entry Vehicles that generate at least moderate lift-drag ratios are much less common. On Earth, they enable runway landing…..









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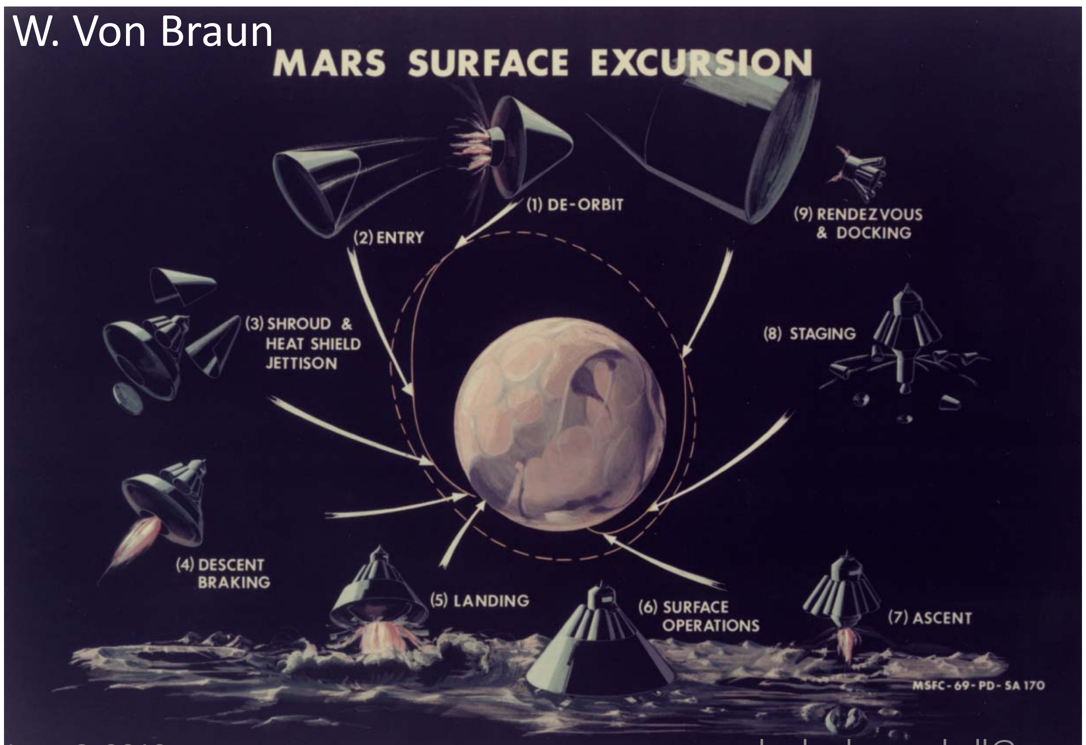
Ideas from the Past can Inform Us

X-20 - Dynasoar

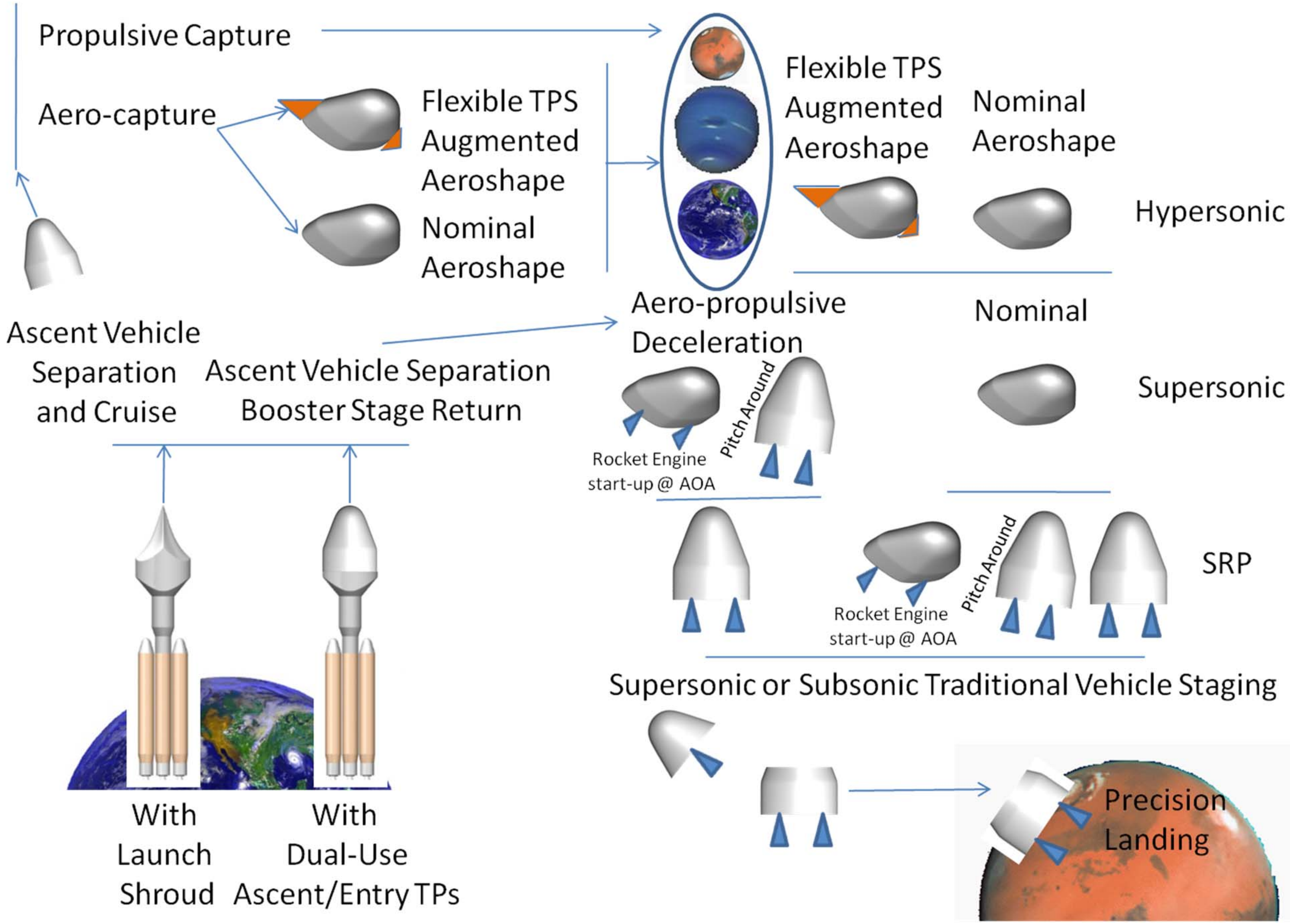
“FIRST” – Rogallo wing entry vehicle

W. Von Braun



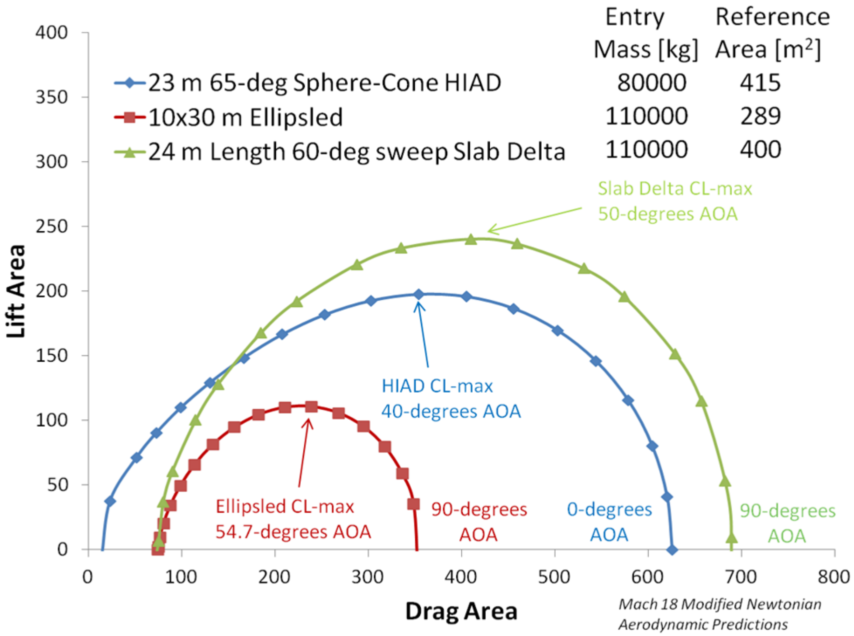
HL-20/Dream Chaser

Advanced Aero-Propulsive Mid L/D



Mars Entry Performance

Human Class Mission



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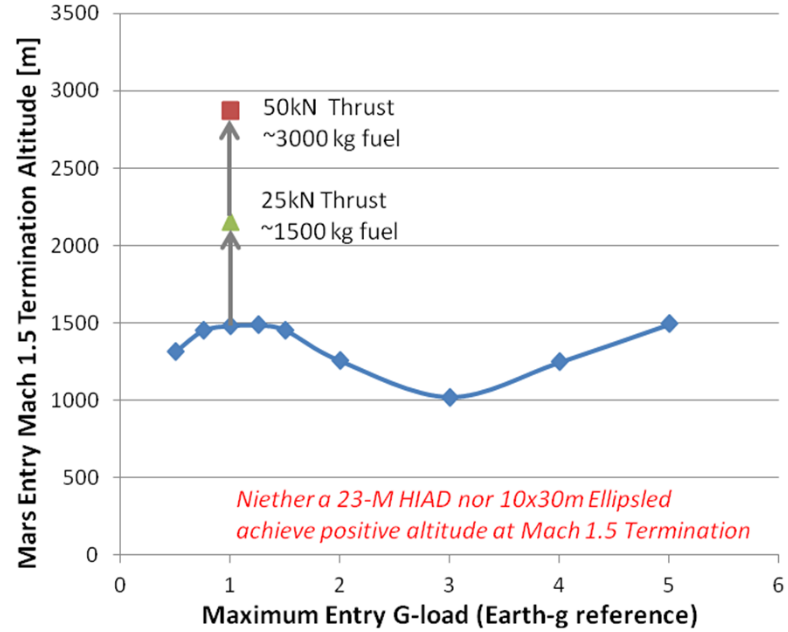

Mars Entry Performance for a slab delta with 60-degree sweep angle and 110000 kg entry mass.

- Mid Lift-to-Drag Entry Vehicles of comparable effective aerodynamic area are *competitive* in altitude performance have *decreased* minimum staging Mach number compared to Low L/D vehicles and will have *decreased* heating rates and dynamic pressures compared to slender Mid L/D vehicles
- Supersonic Aero-Propulsion in combination with Mid L/D vehicles are capable of *superior* altitude performance and decreased Mach number at retro-propulsion staging
- Cost of Development, Qualification and Certification for human system is believed to be *lower* for Advanced Aero-Propulsive Mid L/D Entry Vehicles than for large scale Low L/D systems